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Task I — Special Technical Report 1

COMMUNICATIONS SYSTEMS IMPLICATIONS OF THAI SPEECH

By: KENNETH DIMMICK

Prepared for:

U.S. ARMY ELECTRONICS LABORATORIES
FORT MONMOUTH, NEW JERSEY

CONTRACT DA 36-039 AMC-00040(E)
ORDER NO. 5384-PM-6[illegible]-91

STANFORD RESEARCH INSTITUTE
MENLO PARK, CALIFORNIA
*SRI

June 1965

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PR&C 64-ELN/D-6034
ARPA ORDER NO. 371

By: KENNETH DIMMICK

SRI Project 4240

Approved: B. R. STACK, MANAGER
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SPONSORED BY ADVANCED RESEARCH PROJECTS AGENCY
FOR THE
THAI — U.S. MILITARY RESEARCH AND DEVELOPMENT CENTER
SUPREME COMMAND HEADQUARTERS
BANGKOK, THAILAND

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ABSTRACT

The research reported contributes to the understanding of communication system performance with Thai speech, a tonal language having phonemic values in vowel duration and aspiration. Research results are attained by constructing a 250-word Thai intelligibility test in five similar 50-word forms. Laboratory system simulations and a standard military radio system are used to compare English and Thai word intelligibility under identical communication conditions. The research indicates that Thai speech transmission does not imply unusual system requirements. Thai intelligibility seems to depend on factors different from those in English, and further research is required to establish the nature of these factors.

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I INTRODUCTION

The most commonly employed procedure for the evaluation of speech communication systems for particular applications has been based on how well a given system transmits intelligible speech under specific operational conditions. While considerations of bandwidth requirements, effective range, etc. are of great importance, these considerations are secondary to intelligible speech transmission.

One task of the SEA CORE effort in Thailand has placed special emphasis on the communications requirements in Southeast Asia and on the evaluation of existing systems with respect to satisfying these requirements. The specific objectives of Task I, Sub-Task 4, of the Stanford Research Institute effort in the SEA CORE project were (1) to determine the limitations imposed on communication systems by Thai speech, and (2) to determine the capabilities of certain voice communications systems to transmit intelligible Thai speech as compared to their capabilities to transmit English speech.

In order to determine if spoken Thai imposed any significant hindrance to voice communication over radio systems, or if Thai posed requirements for specially designed equipment, it was necessary to develop some means of quantifying the intelligibility of received Thai. Moreover, the message utilized in such a testing procedure should possess certain known and specifiable characteristics.

Efforts toward evaluating speech communication devices in the United States over the past 25 or more years have resulted in concepts and methodologies for intelligibility testing.[1,2,3,4] Obviously, the most straightforward approach to evaluating communication-system implications of Thai speech was to develop intelligibility testing techniques for spoken Thai. While procedural guidelines for English intelligibility are well established, there were no known tests that were directly applicable to Thai. Generation of the required test instrument was necessarily based on an understanding of the phonology or sound system of spoken standard Thai. The essential phonological characteristics of Thai are presented in the following section.

II PHONOLOGY OF STANDARD THAI

Standard Thai (Siamese) is the national spoken language of Thailand. It is characteristic of the dialect spoken in Bangkok, and to a large extent it is the dialect of the entire Central Plain Region of Thailand. Thai has some status as a second language in neighboring countries. The actual number of native speakers has been conservatively estimated at 18,000,000.[5]

The phonology of Thai differs from that of English in several important ways. Among the marked differences are:

(1) The phonemic nature of aspiration in Thai

(2) The phonemic use of vowel duration

(3) The use of five phonemic tones.

The segmental phonemes of Thai are presented below in the system and notation of Haas:[6]

CONSONANTS[6]

Stops	Bilabial	Dental	Palatal	Velar	Glottal
Voiced unaspirated	/b/	/d/		/-g/*†	
Voiceless Unaspirated	/p-/	/t-/	/c-/	/k-/	/ʔ/
Voiceless aspirated	/ph-/	/th-/	/ch-/	/kh-/	
Spirants					
Voiceless unaspirated	/f-/	/s-/			/h-/
Sonorants					
Voiced semivowels	/w/		/j/		
Voiced nasals	/m/	/n/		/ŋ/	
Voiced lateral		/l-/			
Voiced trill or retroflex		/r-/			

* A number of linguists maintain that this phoneme is unvoiced, /-k/. See Abramson, Arthus S., "The Vowels and Tones of Standard Thai: Acoustical measurements and experiments," Int. J. Am. Linguistics, 28, V-146 (1962).

† The /-/ indicates the position of the phoneme in the syllable; e.g., /-g/ occurs only in the terminal position and /p-/ occurs in the initial position. Absence of the dash indicates that the phoneme may be either initial or final in the syllable.

VOWELS[6]

	Front	Central	Back
	Unrounded		Rounded
High	/i/,/ii/,/ia/	/y/,/yy/,/ya/	/u/,/uu/,/ua/
Mid	/e/ /[illegible]	/ə/,/əə/	/o/,/oo/
Low	/ɛ/,/ɛɛ/	/a/,/aa/	/ɔ/,/ɔɔ/

Owing to allophonic variations, the precise quality of the vowels may change somewhat, especially in connected discourse. For example, /i/ may be [i], but often is [I]; /ii/ is almost always [i:].

TONES

Additional distinctive utterances are generated in Thai by the use of five phonemic tones. The tones are schematically represented below in terms of a general display of the pitch of the voice as a function of time. The vertical line represents the normal pitch range of the speaking voice. The horizontal or semidiagonal lines indicate the pitch contour during the production of a vowel on a given tone. For example, a vowel produced on the middle tone is produced with a relatively stable pitch in the lower third of the pitch range. A vowel in falling tone is begun in the upper half of the pitch range and then falls to a very low level. Tonal contrasts are relative, and the patterns presented here are only intended to indicate the general pitch contours associated with the tones.

SCHEMATIC REPRESENTATION OF TONES OF THAI[6]

In addition to the five phonemic tones, there is a sixth tone of emphasis that may be imposed on any of the basic tones. The emphatic tone is pronounced at a slightly higher pitch than the corresponding normal tone. The emphatic tone may perhaps be better considered as an auxillary prosodic feature that may be imposed on any one of the five phonemic tones to denote the specific exclamatory nature of the utterance.

PERMITTED INITIAL CONSONANT CLUSTERS[6]

	/p/	/t/	/k/	/ph/	/th/	/kh/
/l/	/pl/		/kl/	/phl/	-	/khl/
/r/	/pr/	/tr/*	/kr/	/phr/	/thr/*	/khr/
/w/			/kw/			/khw/

The structure of Thai is such that each syllable begins with a consonant or consonant cluster. Syllable termination may be with a vowel, vowel cluster, nasal, off-glide /w/ and /j/, or one of four stop consonants: /b/, /d/, /k/ (or the final /g/, as Haas[6] maintains), and the /ʔ/. When the syllable terminates with a vowel or vowel cluster, it is necessary to remember that the vowel or vowel nucleus will have an associated phonemic tone.

This brief summary of Thai phonology, with emphasis on segmental phonemes and the five phonemic tones, provides a background for the discussion of test construction which follows.

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* /tr/ and /thr/ occur very rarely in Thai. Indeed, the occurrence of /thr/ may be limited to one instance.[6]

III THAI INTELLIGIBILITY TESTS

A. TEST FORMATS

It was noted in an earlier paragraph that several different tests of English intelligibility have been developed in the United States. Perhaps the best known of these tests are (1) the PAL PB-50's;[1] (2) CID - W-22's;[2] (3) the multiple-choice test of speech intelligibility;[3] (4) the Fairbanks Rhyme Test;[4] (5) the CNC tests;[7] and (6) the Modified Rhyme Test.[8] Each of the above tests is purported to measure speech intelligibility, although the tests may not result in equivalent scores.[9] As a result, each test may have a particular characteristic that makes it especially valuable for a specific application.

Because English intelligibility tests do not produce equivalent scores, and because no one test has been universally adopted for all applications, there was not a single test format after which to model the Thai intelligibility test. Therefore, the developed test format for the Thai intelligibility test possesses some characteristics of several of the previously noted tests. The primary characteristics are:

(1) Stimulus items are monosyllabic words.

(2) Each of the five forms of the test is composed of 50 stimuli.

(3) Each form approximates the phonemic balance of spoken standard Thai.

(4) Each stimulus item is a frequently occurring Thai word and is highly familiar.

(5) Responses to stimuli are written on prepared test forms by the listeners.

(6) The total test vocabulary is 250 words (5 forms x 50 words).

It is obvious that the format of the Thai intelligibility test is quite similar to that of the phonetically balanced word lists in English. Owing to the general lack of previous information on the perception of Thai, it seemed advisable to develop a test structure that would accommodate the phonemic features of Thai and yet be structurally similar to

tests in English. Similarity to English tests was desirable in order to compare English intelligibility functions with those of Thai. This comparison must of necessity be a tentative one, owing to the lack of data on the perception of Thai. Moreover, the relationship of word intelligibility to the effectiveness of communication (sentence or message intelligibility) in Thai remains open for investigation. It is likely that the penalties for misunderstanding a word in Thai are different from those in English. These important areas of investigation were beyond the scope of the present study.

Because Thai is basically monosyllabic in structure and permits considerable latitude in segmental selection within the monosyllabic unit, it appeared that a phonemically balanced word format was appropriate.

1. Determination of Frequency of Occurrence of Thai Phonemes

In order to construct a phonemically balanced word list to serve as a stimulus item for the test, it was first necessary to have the basic count of frequency of occurrence of Thai phonemes (both segmental and tonal) as they occur in spoken standard (Bangkok) Thai. There was no evidence that a previous count of the frequency of occurrence of phonemes in spoken Thai had been made. Therefore, an early step in the conduct of this research program was to make such a count.

The process of determining the frequency of occurrence of phonemes in a language poses some very real problems for which there are no wholly satisfactory solutions. The frequency-of-occurrence statistics resulting from any particular count will depend on the material selected for analysis and how well that material represents a "typical" sample of the spoken language as used by all users of the language. It is obvious that no moderately sized sample is likely to be totally representative of the spoken language as employed by all users of a particular dialect. As a result, most phoneme counts are more or less biased by the nature of the materials selected for analysis.

One procedure which partially circumvents this problem is to base the phoneme count on an analysis of the most frequently occurring words in a language. The supposition is that the phonemic strings making up most frequently occurring words will provide a relatively unbiased basis for determining the frequency of occurrence of the various phonemes. This assumption is only partially valid, inasmuch as the source material for the word count will substantially influence the rank orders of the various words in the language. The effects are theoretically still present at the phonemic level.

Another problem arises in selecting a procedure for determining the phoremic elements in a word or utterance. If the analysis is based on recordings of actual utterances by native speakers, it will result in data which reflect idiosyncratic uses, i.e., various kinds of assimilations and unstressing phenomena that occur in continuous discourse. While the above factors may be considers "contaminating" influences, they are, indeed, part of everyday conversational speech.

Another approach is to analyze each word as uttered in citation manner, or to utilize a phonemic transcription as it appears in a pronouncing dictionary, which presumably represents the most common pronunciations used by the educated speakers of a dialect. Because speech communications are seldom if ever conducted in citation manner, this procedure is somewhat less than ideal.

For purposes of the investigation reported herein, it was decided to base the phonemic analysis of selected words on the standard Thai pronunciations reported by Haas.[6] The decision was based on two factors. First, the time and expense involved in getting and transcribing the utterances of many Bangkok Thai speakers would have been excessive, with little assurance that the final analysis would be substantially superior to that resulting from the procedure employed. Second, because monosyllabic words were used as stimulus items, it was likely that they would be uttered in essentially citation form, even if couched in a carrier phrase. A stimulus item in a neutral carrier phrase tends to maintain much of its full stressed value. In view of these considerations, the phonemic transcriptions of Haas seemed adequate and appropriate.

The selection of appropriate material for phonemic analysis posed a more difficult problem. An earlier exploratory effort was aimed at determining the frequency of occurrence of Thai phonemes in a selected military vocabulary. The rationale was that since the SEA CORE project was focused on military communications, a vocabulary of military terms would be most appropriate. While the rationale may be theoretically sound, it does not take full cognizance of the structure and etymology of Thai words. For example, one could expect a military vocabulary to have a number of entries dealing with weapons or guns, and the Thai equivalent would be likely to contain the stem /pyyn/. This syllable forms part of the Thai word for pistol, rifle, artillery, bullet, etc. Similarly, acts associated with embarking, flying, disembarking, etc. from an airplane, and the noun itself, contain the element /khrya bin/. The syllable /rod/ is likely to occur in the Thai expression for any motorized means of ground transportation and for many acts associated with this means of travel.

The result of basing a frequency-of-occurrence count on a specialized vocabulary is that certain phonemes will have an unusually high frequency of occurrence, owing to their role in certain elements used in compounding. In essence, the frequency-of-occurrence count displays a strong bias characteristic of military speech, but it may not be representative of the phonemic occurrences in the language in general.

A more appropriate approach is to determine the frequency-of-occurrence count of phonemes from some sample that is more representative of the language. In the present study, two approaches were used. The first source was a list published by McFarland[10] of the 1000 most commonly used words in Thai. This count was based on over 150,000 words as they appeared in general Thai literary works. The 1000 most frequently used words were transcribed into phonemic symbolization (the system of Haas[6]), and a frequency of occurrence count for the phonemes was determined.

The McFarland list of the 1000 most oftenly used words could not be considered as strongly representative of coversational or spoken Thai.

An analysis of the word list revealed that many literary, elegant, and elaborate expressions were included. While such expressions undoubtedly appear frequencly in the Thai literature, they are not typical of conversational speech.

A second vocabulary was obtained and transcribed phonemically. This word list, "Thai Word Lists - I, II"[11] was obtained from the Bangkok office of the British Chamber of Commerce. The vocabulary is made up of approximately 1800 words "...chosen for their frequency and usefulness...". Although the selection procedures used in the compilation of the basic Thai vocabulary could not be determined, it was assumed that the vocabulary more closely approximated conversational Thai than did the McFarland list.

A Thai resident in Bangkok was engaged to review both word lists and to provide an opinion as to the familiarity of the words. The Thai informant maintained that all words in the Thai word list were, indeed, in common everyday usage. To the contrary, a number of words from the McFarland list were not in his vocabulary; and the informant, who is the headmaster of a school in Bangkok, can be considered as a rather well-educated individual.

Figure 1 shows a comparison of the rank orderings of Thai phonemes for the McFarland,[10] Thai word lists,[11] and a military vocabulary.[12] The phoneme order on the abscissa was derived from the McFarland count. The agreement between the McFarland ordering and that obtained from the Thai word list is rather high. The military vocabulary produced a phoneme ordering that was obviously different from either of the others.

Because the agreement between the McFarland list and the Thai word list was reasonably good, a decision was made to use the McFarland list as a basis for calculating the frequency of occurrence of the various phonemes in the test lists. The justification for this decision was that the McFarland list was based on a large sample of Thai words (167,546 words from 30 sources), and therefore the original sample could be better specified than either of the other two counts. Moreover, the vocabulary

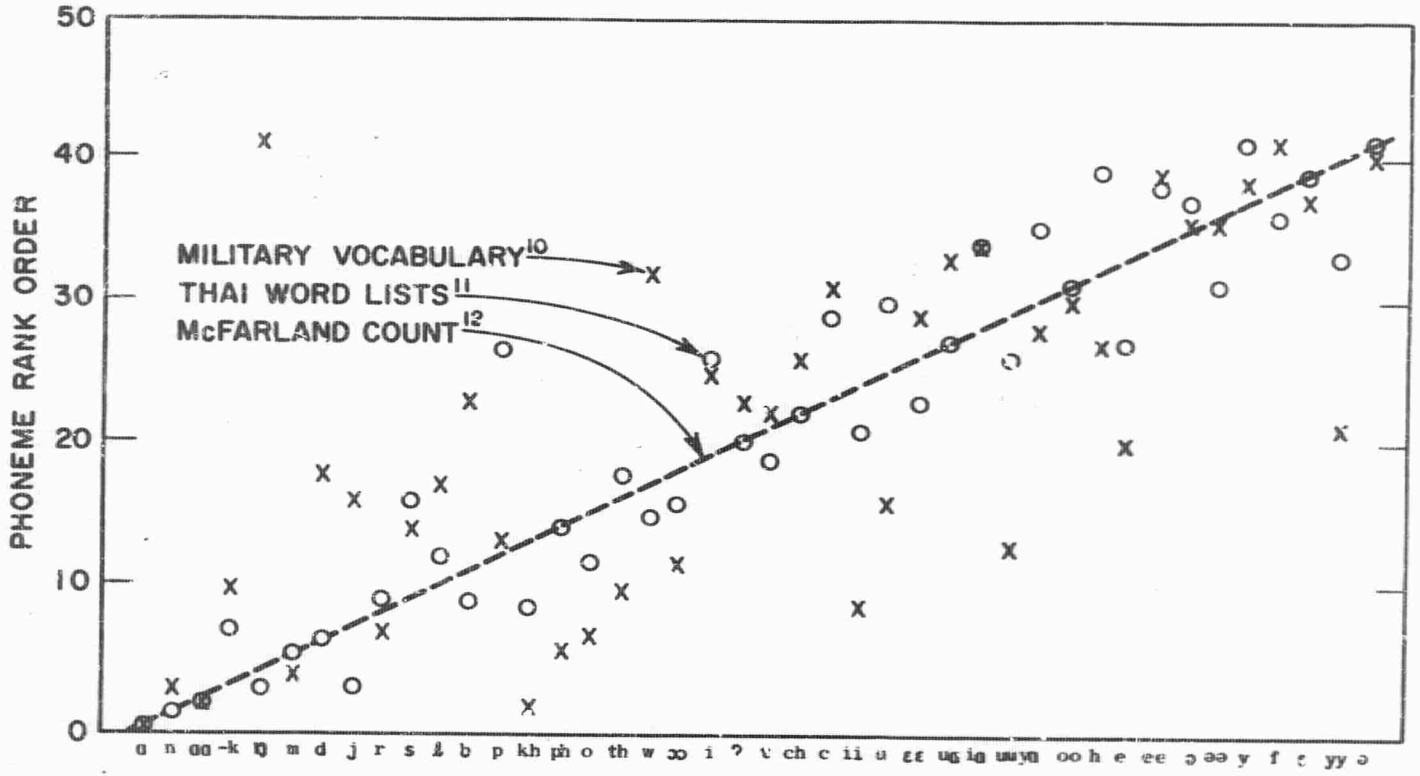


FIG. 1 RANK ORDER OF PHONEME TYPE FOR THREE WORD COUNTS

Plot is of the rank-ordered frequency of occurrence of the McFarland, Thai word lists, and a military vocabulary. Data from the McFarland count form the diagonal.

based on a large sample produced substantially the same phoneme ordering as did the smaller yet highly familiar word list.

The analysis of the distribution of phoneme types and the syllable structure of the McFarland list of the 1000 most frequently used words provided the following descriptive observations:

(1) There were 3534 segmental phonemes in the 1000 words, with a mean of 3.54 phonemes per entry.

(2) There were 367 monosyllabic words in the list, with a mean of 2.8 segmentals per entry.

(3) The distribution of tones within the 1000 words was:

Mid --- 560 or 44%
Low --- 238 or 18.7%
Falling --- 193 or 15.1%
High --- 155 or 12.2%
Rising --- 124 or 9.7%

(4) The rank ordering of segmental phonemes is contained in Figure 1.

2. Description of Test Items

It was pointed out earlier that the intelligibility test was to be designed around five forms or word lists of 50 words each. The analysis of the McFarland list provided a basis for statistically determining the segmental and tone composition or distribution of each of the 50-item word lists. Obviously, it would be highly unlikely that actual and familiar words could be found which would completely satisfy the statistical requirements, nonetheless, the statistical description served as a guideline for constructing the word lists.

The guidelines developed called for the following distribution of segmental phonemes and tones for each 50-item word list:

Consonants (Occurrences per 50 words)	Vowel Nuclei (Occurrences per 50 words)	Tones*
n = 11	a = 13	Mid tone = 15
k = 8	aa = 10	Low tone = 11
ŋ = 7	o = 3	Falling tone = 12
... = 7	ɔɔ = 3	High tone = 7
d = 7	i = 3	Rising tone = 5
j = 6	ii = 2	
r = 6	u = 2	
s = 4	ɛɛ = 1	
l = 4	ua = 1	
b = 4	ie = 1	
kh = 4	uu = 1	
ph = 3	ya = 1	
th = 3	oo = 1	
w = 3	e = 1	
? = 3	ee = 1	
t = 3	ɔ = 1	
ch = 2	ee = 1	
p = 2	y = 1	
c = 2	ɛ = 1	
h = 1	yy = 1	
f = 1	ɵ = 1	

The above tabulation served as a guide for constructing the five lists of phonemically balanced words. This guideline suggests a statistical ideal for a 50-item list. It was not possible to satisfy the requirements of the "ideal" or optimum in each of the lists; however, the balance in each of the lists did correspond reasonably well with the phoneme distribution outlined above.

The actual words used as stimulus items were selected from the Braine-Hartnell basic Thai vocabulary.[11] Words were chosen from this source because of the greater familiarity of the words. It was pointed out earlier that the basic Thai vocabulary is made up of quite common, frequently used words. High word familiarity is considered desirable in a test of this kind.[2]

---

* Tone frequency of occurrence reported here was based on the count of monosyllabic words in the McFarland list.[10]

B. TEST CONDITIONS

After the test items had been selected they were submitted to a panel of three instructors of Thai from the Defense Language Institute of Monterey for approval and comment. The instructors, all originally from Bangkok, agreed that the word lists were appropriate monosyllabic words of high familiarity. (The word lists are given in Appendix A.)

1. Speakers and Recording Conditions

The instructors then served as speakers while master recordings were made of the test forms. During the recording session, two instructors monitored the recorded reading of the third speaker. If an item was not pronounced acceptably, the speaker was requested to repeat the item. After the recording session the speaker listened to his own recording and rated the acceptability of the items. The end product of the recording and monitoring sessions was a master recording of each of the three speakers as he read each of the five forms of the intelligibility test.

The recordings were made under carefully controlled conditions. The speaker was seated in a double-walled Industrial Acoustics Corporation 1202A sound room. Stimulus intervals of five seconds were cued by a timing light attached to the microphone boom. The recording microphone, Omega condenser, was fed into an Ampex console tape recorder, Model 351. A signal-to-noise ratio (S/N) in excess of 48 dB was achieved on the master tape recordings.

The S/N figures quoted in this report were arithmetically derived from physical measures of signal-plus-noise and noise in the absence of signal. Here the "signal" value is the mean peak intensity of the stimulus words in a list or collection of lists as observed on a Hewlett-Packard 400-L VTVM. Deviations from the mean value of peak intensity were less than or equal to 2 dB for English stimuli and 4 dB for Thai stimuli, when measured in the clear or master tape recordings.

A first-generation dub of the master recording was prepared for test administration. Various randomizations were prepared for each of the recordings produced by each of the three speakers. First-generation

dubs were used throughout the test development and evaluation investigation. The master recordings were carefully stored in NETIC metal containers and were used only in the preparation of dubs. The randomized versions of the recordings of the three speakers were then cast into matrices for presentation to listeners. The purpose of the initial tests was to select one of the three speakers for use during the course of the entire test program.

It is generally agreed that a large number of speakers should be employed in intelligibility testing, although in reality this seldom occurs. Because of the time limitations and the basic nature of the research in progress it was deemed more advisable to employ only one speaker. The precedent for using one speaker is well established.[2,4]

2. Test Facility

A decision had been made earlier in the project to attempt to do most of the test development and evaluation at SRI, Menlo Park, rather than in the Bangkok facility. The decision was based on the availability of Thais in the Menlo Park area and the desirability of performing the bulk of the work under carefully controlled conditions available in the Menlo Park facility. Moreover, it appeared that a greater amount of useful data could be obtained by maintaining the major portion of the project direction and effort at Menlo Park.

3. Listeners

Citizens of Thailand were recruited from the foreign student population in the San Francisco Bay area to serve as listeners. A total of 16 listeners were employed during the course of the testing program. All 16 had lived all or part of their lives in Bangkok and spoke the standard Bangkok dialect. All listeners were screened for hearing impairments, and no impairments were found. The listeners were paid for their services. Both male and female listeners were employed.

4. Test Procedure

The listeners were instructed in the general nature of their listening task and the appropriate mode of response. They were requested to write in Thai the stimulus word uttered by the speaker. They were

cautioned to listen carefully and to "guess" if they were not entirely certain. The listeners were presented with sample lists and were administered several training lists.

Test tapes for the three speakers were prepared with S/N of -6, 0, +6, and +12 dB, and with no noise added. Test administration was to two groups of four and one group of eight listeners. The results indicated few differences among the three speakers across the five forms of the intelligibility test. However, speaker 2 produced slightly more homogeneous test responses and so was selected as the speaker for the major portion of the test development and evaluation.

C. ANALYSIS OF RESULTS

Figure 2a displays the mean intelligibility scores obtained from the 16 listeners for the lists recorded by speaker 2. The ordinate is percent correct intelligibility and the abscissa is S/N.

For the purposes of comparison, Figure 2b is included. This figure shows mean intelligibility scores obtained from 18 listeners and one speaker for a recently developed test of intelligibility in English.[8] Data points are similar, and it can be seen that there is considerable similarity between the magnitudes and shapes of the intelligibility curves.

The data plotted in Figure 2a imply that the five forms of the intelligibility test are not equivalent, that statistical differences do exist. However, the range of scores is similar to that obtained when different forms of English intelligibility tests are compared.[13] Table I summarizes the results of a three-way analysis of variance of the obtained test scores. Significant F-ratios were obtained for test forms, S/N ratios, subject and test form interaction, and condition and test form interaction. This is to say that observed differences in test scores between forms cannot be attributed to chance factors and that in fact there are "real" differences among scores obtained for various S/N ratios

as well as among scores obtained with different forms, subjects, and conditions. The significant differences for various S/N ratios simply reflect the desirable differentiation between communication systems of differing qualities; significant differences associated with test forms suggest that further development is necessary before the forms can be regarded as "equivalent test forms."

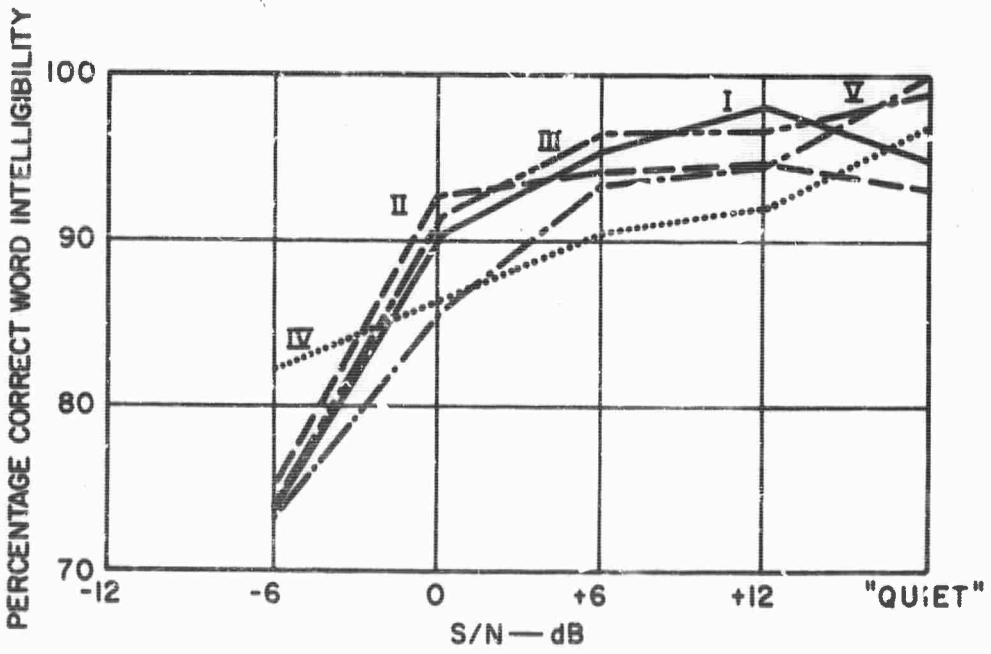


FIG. 2(a) CORRECT THAI WORD INTELLIGIBILITY FOR FIVE FORMS OF THAI INTELLIGIBILITY TESTS AS A FUNCTION OF S/N RATIO

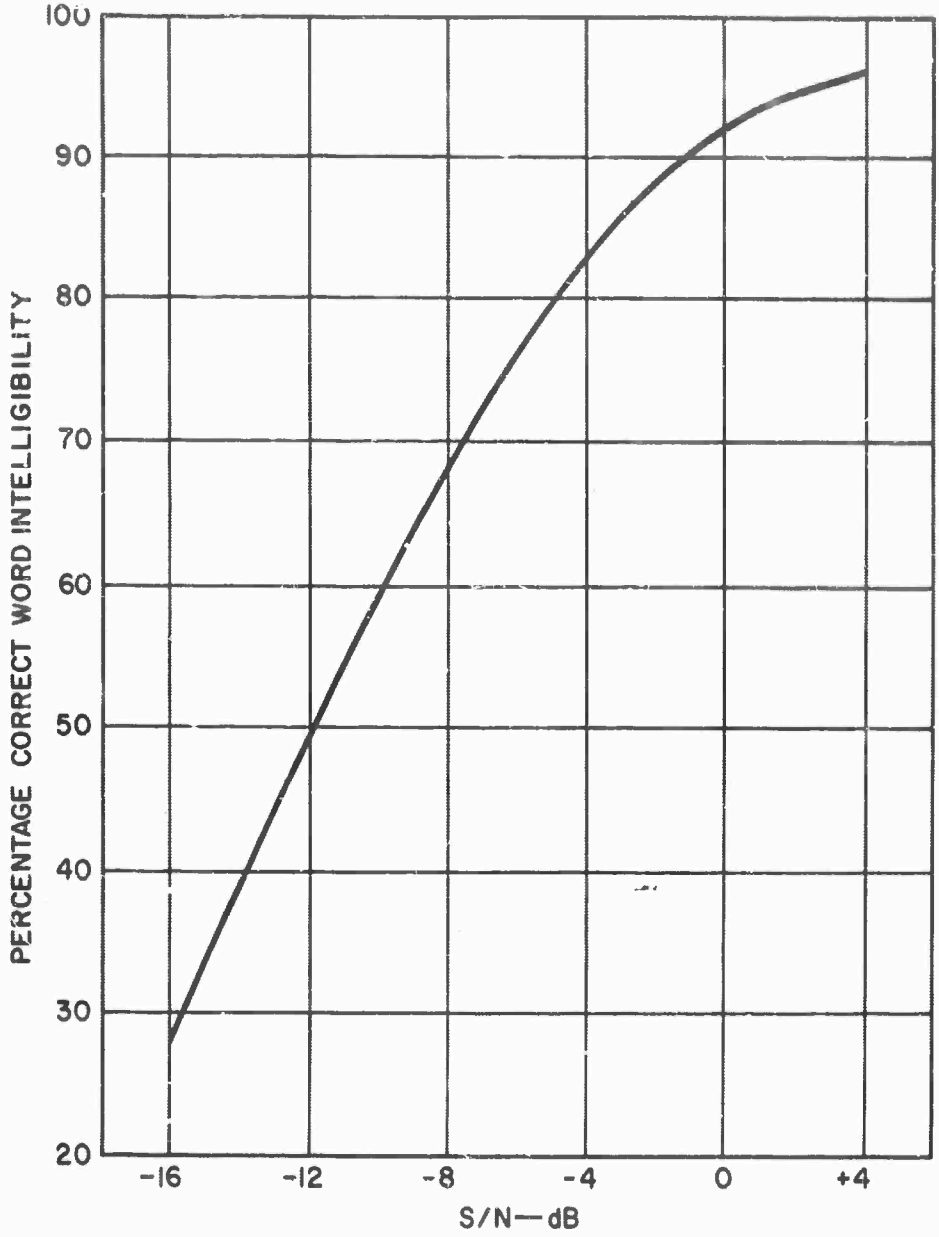


FIG. 2(b) INTELLIGIBILITY AS A FUNCTION OF S/N RATIO FOR MODIFIED RHYME TEST

(Adapted from A.S. House et al .)

Table I

ANALYSIS OF VARIANCE FOR
THAI INTELLIGIBILITY TEST FORMS

	df	M.S.	F	
Subjects (S)	14	91.56	---	
Test Form (T)	4	282.78	13.19	$P < 0.001$
S/N Ratio (C)	3	3982.84	304.73	$P < 0.001$
S x C	42	13.07	1.23	
S x T	56	21.44	2.02	$P < 0.01$
C x T	12	167.02	15.77	$P < 0.001$
S x C x T	168	10.59		
Total	299			

Table II shows the average percent correct response for 15 listeners and is arranged according to test form and S/N level of presentation. This table displays some of the relationships which are generally expected to exist among intelligibility scores obtained under conditions of reduced S/N. Specifically, the mean intelligibility score is substantially reduced and the standard deviation (SD) of the mean is considerably increased.

Again, for general comparative purposes, data from the House et al.[8] study are presented in Table III for direct comparison with the data obtained in this investigation. It must be noted, however, that the data are not directly comparable in S/N ratios and test formats. The House test is a multiple-choice test (essentially a six-alternative, forced-choice test), and smaller variances can be expected to characterize the scores from a limited response matrix.

It can be seen from Table III that similarities exist between the data derived from these two investigations. The table is not intended to specify a definite relationship between Thai and English intelligibility or to suggest that similar intelligibility functions for the two languages will be obtained under identical conditions. Data to be presented later in this report suggest that this is not the case. The

Table II

RESULTS OF THAI INTELLIGIBILITY TESTS FOR FOUR S/N LEVELS

S/N	THAI TEST FORMS (Avg. % Correct Responses) I	II	III	IV	V	Total	Mean	Standard Deviation
-6	74.00	76.53	78.40	82.93	73.33	385.19	77.04	5.09
0	89.73	92.80	91.60	86.93	85.33	446.39	89.28	2.80
+6	95.07	94.27	96.53	90.27	93.33	469.47	93.89	2.09
+12	97.47	94.67	96.67	92.00	94.40	475.21	95.04	1.92
Total:	356.27	358.27	363.20	352.13	346.39			
Mean:	89.06	89.57	90.80	88.03	86.59			

Table III

COMPARISON OF THAI-ENGLISH INTELLIGIBILITY TEST RESULTS AT FOUR S/N LEVELS

Test	S/N	TEST FORMS (Avg. % Correct Responses) A	B	C	D	E	F	Mean	Standard Deviation
Thai Intelligibility	-6	74	77	78	83	73		77	5.09
	0	90	93	92	87	85		89	2.80
	+6	95	94	97	90	93		94	2.09
Modified Rhyme	-8	74	81	69	83	66	79	75	6.1
	0	96	95	94	90	93	92	93	2.2
	+4	98	98	97	92	98	95	96	2.2

comparison provided by Table III demonstrates only that intelligibility in both Thai and English decreased with a reduction in S/N ratio.

D. EFFECTS OF FILTERING ON INTELLIGIBILITY

At this point in the research program considerable data had been collected and analyzed on the intelligibility of Thai under various S/N conditions. While precise comparability between the obtained Thai scores and those reported for English intelligibility could not be established, it was apparent from inspection that some similarities might exist, and that additional investigations should be initiated to explore the range of similarity. At this point a brief series of tests was conducted in which the objective was to determine the effects of filtering on Thai intelligibility. Although the tests conducted were not exhaustive, they did provide some insight into the effects of frequency filtering on the intelligibility of Thai speech.

The tests were administered under six conditions; high-pass filtering, with increasing cut-off frequencies of 1.2, 2.0, and 2.9 kc; low-pass filtering, with decreasing cut-off frequencies of 1.2, 0.9, and 0.7 kc. The frequency response of the reproducing equipment was approximately 40 - 15,000 cps between the 3 dB-down points. The six filtering conditions (including the reproducer characteristics) were equivalent to the following band-pass specifications; 1.2 - 15 kc, 2.0 - 15 kc, 2.9 - 15 kc, 40 - 1200 cps, 40 - 900 cps, and 40 - 700 cps. The tests were conducted in "quiet;" i.e., no noise was added to the test signal. All five forms of the Thai intelligibility test were administered to eight of the original Thai listeners (listeners obtained in the Bay Area). In interpreting the results of this set of experiments it should be remembered that these listeners were very well trained and had been exposed to the test forms numerous times. Of course, various randomizations of the test forms were employed in the experiments.

Recordings of the intelligibility test were passed through two cascaded Allison filters (Model 2AB), which were set at the appropriate cut-off frequencies. The cut-off frequencies and the roll-off characteristics of the filters were verified by examining the output of the filters

with a Bruel and Kjaer spectrum analyzer. Cut-off frequency control is variable with the Allison filter and thus could be adjusted until the precise value desired was obtained. The roll-off characteristic of the pair of cascaded filters was approximately 72 dB per octave beyond the cut-off frequency. The output of the filter bank was recorded on an Ampex 351 recorder, and the recorded filtered speech was then presented to the listeners. A summary of the results obtained is presented in Figure 3.

The solid curves plotted in Fig. 3 show the obtained mean intelligibility scores for the six conditions of high- and low-pass filtering. The dashed curves are similar data on English W-22 PB's (200-word vocabulary) as reported by Hirsh, Reynolds, and Joseph.[14] An extension of the Thai high-pass curve would seem to intersect the low-pass curve at about 1.0 kc, although this intersection was not actually determined. This intersection, or "cross-over" point, determines the cut-off frequency at which high- and low-pass filters would transmit word lists at the same level of intelligibility. Note that data on W-22's suggest an intersection at about 1700 cps and 90% intelligibility; French and Steinberg,[15] using nonsense syllables, reported intersection at 1.9 kc.

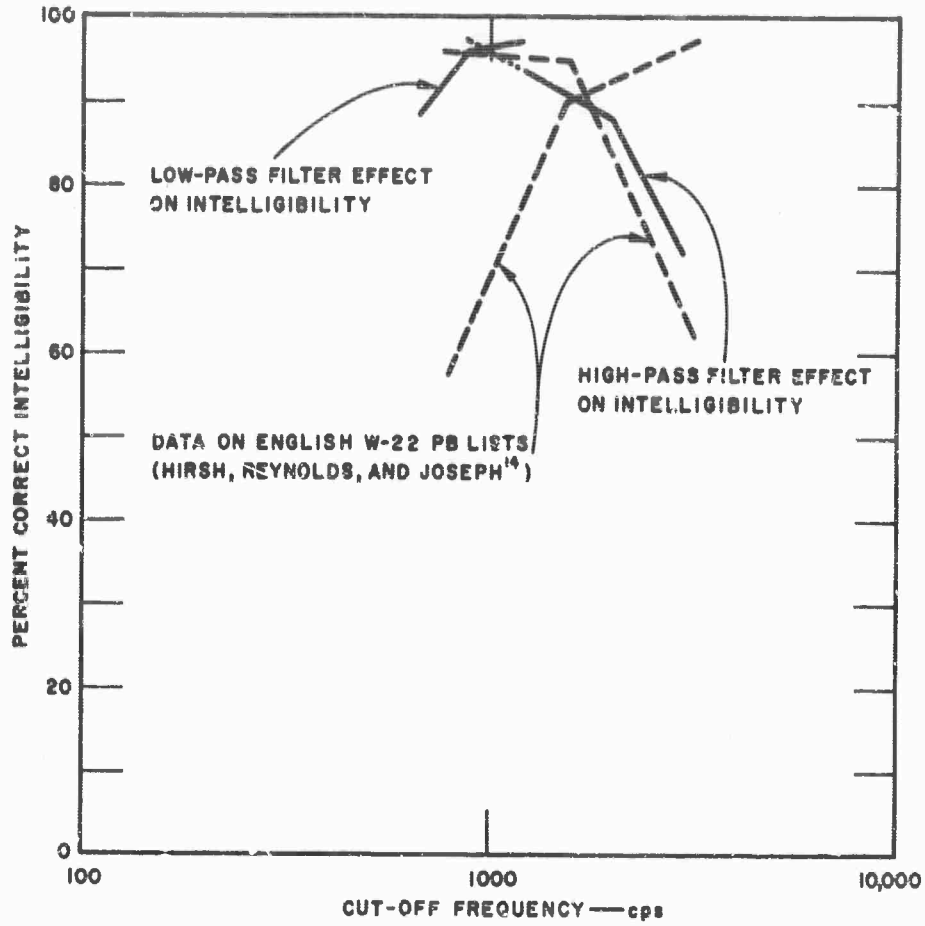


FIG. 3 THAI MONOSYLLABIC WORD INTELLIGIBILITY FOR SELECTED HIGH-PASS AND LOW-PASS FILTER CONDITIONS AND COMPARABLE DATA ON ENGLISH WORD LISTS

IV ENGLISH-THAI COMPARATIVE INTELLIGIBILITY TESTS

A. INTRODUCTION

At this point in the research program a request[16] was received from the contracting agency to conduct a specific series of tests in which English and Thai intelligibility were to be compared. (See Appendix B for a copy of the text of the request.) The request was motivated by the preliminary findings of this research, which had indicated a relatively high degree of similarity between Thai and English intelligibility test scores under comparable S/N conditions. The directive from the COTR was received in late November 1964, and effort was initiated in response to the directive almost immediately.

Test tapes were prepared in accordance with the specifications contained in the directive for administration to Thai listeners. The tape preparation was completed during the first week of December 1964.

The tests and results reported herein were incorporated in a larger test program that was designed to:

(1) Compare English and Thai intelligibility over various system configurations

(2) Compare intelligibility scores obtained from native (residents of Bangkok) speakers of Thai and scores obtained from the Thai population (primarily foreign students) available at SRI, Menlo Park

(3) To obtain additional data on the performance of the developed Thai intelligibility test--particularly with a different and unexposed Thai population.

The test results reported herein were obtained in Bangkok December 11-18) and Menlo Park (December 26 - January 26). The results are based on the scores produced by three populations: Bangkok Thai, U.S. Thai, and native speakers of American English.

B. PROCEDURE

Master tapes were prepared for both the Thai and the English intelligibility tests. The tests were recorded under laboratory conditions on an Ampex 351 recorder. One speaker for each language was employed. The master recordings had a S/N ratio of over 45 dB. Stimulus items were recorded at five-second intervals and were judged by both the speaker

and a panel of at least two native speakers of the language in question, Thai or English. Unacceptable items were re-recorded until judged acceptable by the panel. Various randomizations of the word lists were dubbed from the master recordings. The dubbed recordings were used for presentation to the listener crews.

C. TEST FORMATS

1. Thai Intelligibility Test

The Thai intelligibility test has been described in Section III of this report. In the present tests, all five forms were employed. The intelligibility scores reported in the following section are means for all lists and all listeners.

2. English Intelligibility Test

A number of different kinds of English intelligibility tests exist, and any one of them could have been administered in this test program. However, in order to provide the greatest theoretical comparability, the Central Institute for the Deaf (CID) Auditory Test W-22 was used.[2] This test has been used extensively in intelligibility research and possesses many of the characteristics of the Thai test. Specifically, the test vocabulary is made up of highly familiar monosyllabic words. Each 50-word list approximates the frequency of occurrence of the phonemes in American English. The various word lists are purported to produce equivalent intelligibility scores. Stimulus items are typically presented in a carrier phrase; in the present experiments the carrier phrase was, "You will write the word _____."

D. TEST CONDITIONS

1. Listeners

The response of the following three groups of listeners are presented in this study.

(1) Ten members of the Royal Thai military services served as listeners for the tests administered in Bangkok.

(2) Five to seven native speakers of Thai, now residing in the Menlo Park area, participated in the tests. These listeners assisted in earlier tests during the development of the Thai intelligibility test. They are speakers of Bangkok Thai and citizens of Thailand.

(3) Ten young male adults recruited from the student population at Stanford University served as subjects for the English intelligibility tests.

All listeners were given an audiometric screening test to detect any hearing impairments in the so-called speech frequency range. One subject in Bangkok was rejected because of impaired hearing.

2. Test Facilities

The tests in Bangkok were conducted in a mobile van located at the T-van complex. The van was situated as far away from the power source (generators) as was practical. Test conditions were far from ideal, owing to the limited space within the van and the general discomfort attributable to the lack of air conditioning. Moreover, matched headphones were not available in Bangkok.

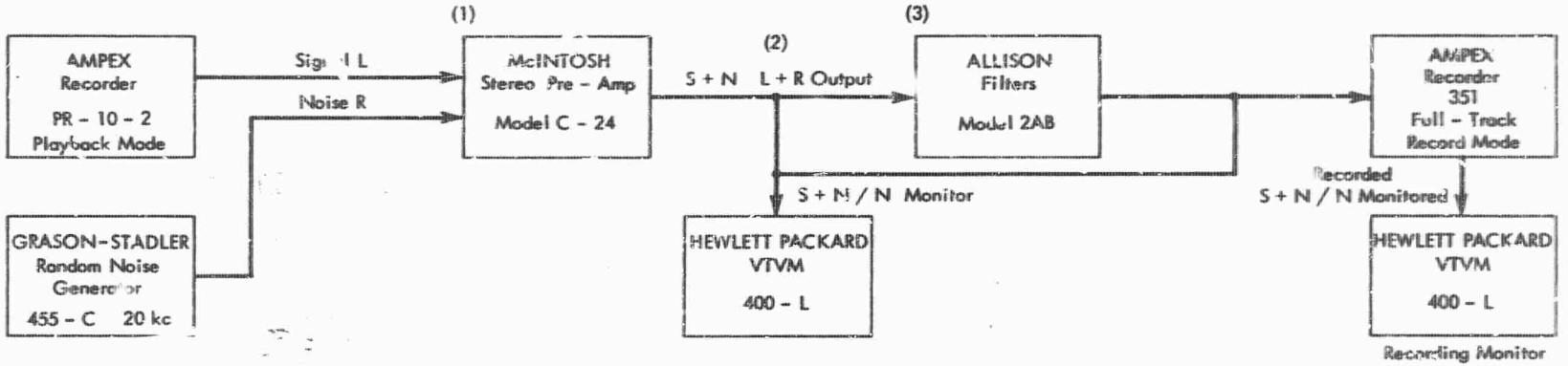
All tests conducted at Menlo Park were administered in a heavily sound-treated test chamber (IAC single-walled unit). The headphones were all of the same type and model number (Sharpe, HA-10).

E. RESULTS

The results obtained in the test program are presented in tabular form according to test conditions, as specified in the referenced directive.[16] All test conditions specified in the directive were achieved with but minor deviation. (See Figures 4, 5, 6, for a schematic representation of the systems employed.) The greatest deviation from specifications was in Condition B, which called for 80 dB attenuation of a 200-cps band between 1175 and 1375 cps (see paragraph 3b of Appendix B). Attenuation of 80 dB for such a narrow band was not possible with the available electronic filters; we were able, however, to attenuate the 200-cps band in excess of 42 dB. Intelligibility differences between the specified and the obtained attenuation can be expected to be minimal, if measureable.

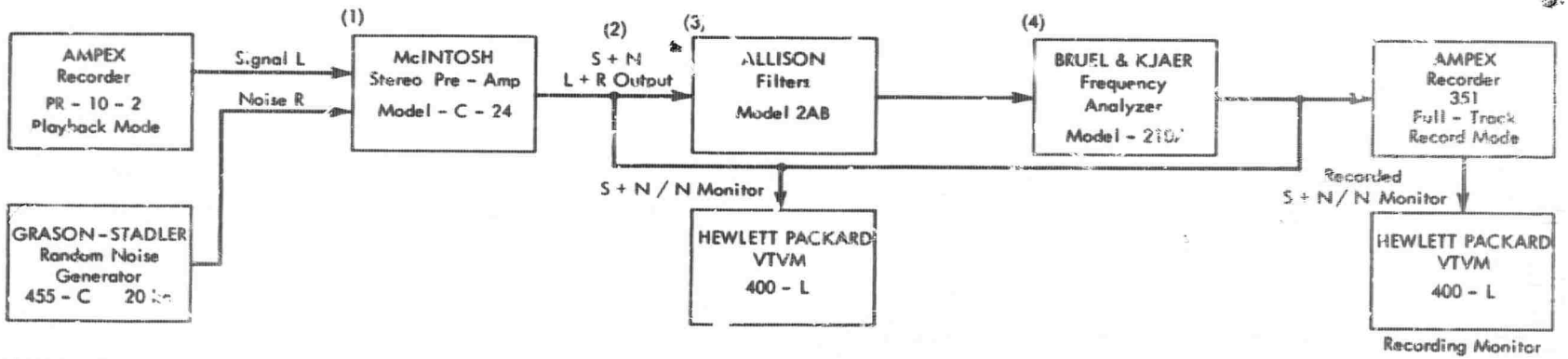
1. Condition A

Condition A of the directive called for: "Comparison of Thai and English intelligibility when passed through a bandpass of 3.1 kc at 6 dB down, 4.2 kc at 60 dB down (shape factor: 2/1) with center frequency of 1350 cycles."[16] (See Figure 4.)



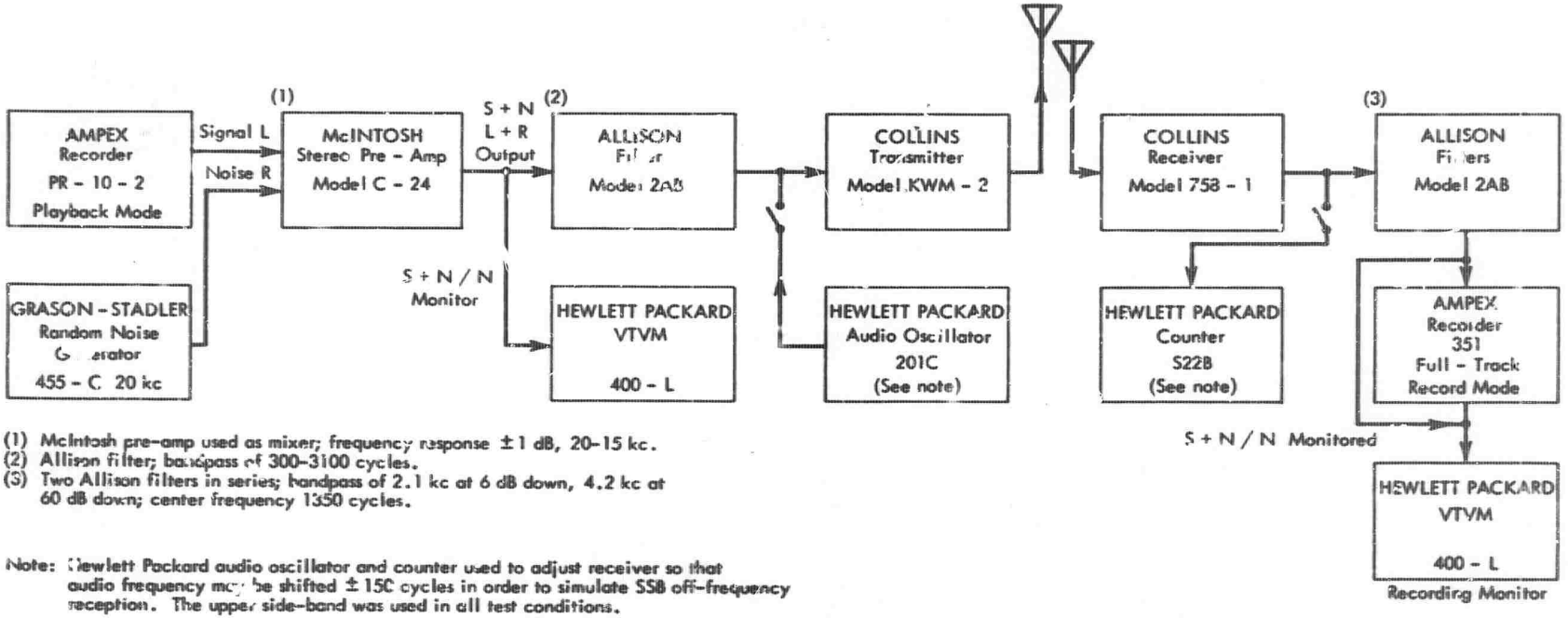
(1) McIntosh pre-amp used as mixer; frequency response ±1 dB, 20-15 kc.
(2) S/N: + 12, + 6, and 0 dB, computed from S + N/N measurements.
(3) Two Allison filters in series; bandpass of 2.1 kc at 6 dB down, 4.2 kc at 60 dB down; center frequency 1350 cycles, attentuation approximately 72 dB/octave.

FIG. 4 CONDITION A CONFIGURATION



(1) McIntosh pre-amp used as mixer; frequency response ± 1 dB, 20-15 kc.
(2) S/N: +12, + 6, and 0 dB, computed from S + N/N measurements.
(3) Two Allison filters in series; bandpass of 300-3100 cycles.
(4) Bruel & Kjaer frequency analyzer set for frequency rejection of 200 cycles, center frequency 1270 cycles, attenuation approximately 60 dB (notch, 1175-1375 cycles).

FIG. 5 CONDITION B CONFIGURATION



(1) McIntosh pre-amp used as mixer; frequency response ±1 dB, 20-15 kc.
(2) Allison filter; bandpass of 300-3100 cycles.
(3) Two Allison filters in series; bandpass of 2.1 kc at 6 dB down, 4.2 kc at 60 dB down; center frequency 1350 cycles.

Note: Hewlett Packard audio oscillator and counter used to adjust receiver so that audio frequency may be shifted ±150 cycles in order to simulate SSB off-frequency reception. The upper side-band was used in all test conditions.

FIG. 6 CONDITION C AND D CONFIGURATION

Listeners	S/N = +12	+6	0
U.S. Thai (mean % correct)	82.1	79.7	64.8
Bangkok Thai	74.4	71.6	54.3
(Mean Thai intell.)	(76.9)	(74.3)	(57.8)
English intelligibility	55.2	45.1	35.5
Difference in mean intelligibility	21.7	29.2	22.3

2. Condition B

Condition B of the directive called for: "Comparison of Thai and English intelligibility when passed through a bandpass of 300-3100 cycles (standard telephone circuit) with a 200-cycle segment between 1175 to 1375 cycles attenuated 80 dB."[16] (See Figure 5)

Listeners	S/N = +12	+6	0
U.S. Thai (mean % correct)	94.6	89.2	85.4
Bangkok Thai	83.4	81.4	75.2
(Mean Thai intell.)	(90.9)	(84.0)	(78.6)
English intelligibility	66.5	57.8	48.6
Difference in mean intelligibility	24.4	26.2	30.0

3. Condition C

Condition C of the directive called for: "Comparison of Thai and English intelligibility when passed through a bandpass of 2.1 kc at 6 dB down, 4.2 kc at 60 dB down (shape factor 2:1) with center frequency of 1350 cycles and all audio frequencies shifted +150 cycles. Condition similar to off-frequency reception of a SSB signal."[16] (See Figure 6.)

Listeners	S/N = +12	+6	0
U.S. Thai (mean % correct)	76.9	76.6	61.0
Bangkok Thai	67.4	65.8	46.6
(Mean Thai intell.)	(71.3)	(70.2)	(52.5)
English intelligibility	56.2	40.0	31.7
Difference in mean intelligibility	15.1	30.2	20.8

4. Condition D

Condition D called for: "Repeat test 3c (Condition C) but with audio frequencies shifted -150 cycles."[16] (See Figure 6.)

Listeners	S/N = +12	+6	0
U.S. Thai (mean % correct)	82.9	79.9	65.4
Bangkok Thai	73.8	69.4	59.6
(Mean Thai intell.)	(76.8)	(72.9)	(61.5)
English intelligibility	58.8	47.3	37.1
Difference in mean intelligibility	18.0	25.6	24.4

F. SUMMARY AND COMMENTS

A comparison of Thai and English intelligibility was made over four system configurations at three S/N ratios. The obtained intelligibility scores are presented as mean percentage correct responses to the stimulus items. Under the test conditions employed in this investigation, the Thai intelligibility scores were higher than the English intelligibility scores. A reduction of S/N was accompanied by an expected reduction in intelligibility. The attenuated intelligibility scores as a function of reduced S/N ratios characterized both Thai and English.

In the interpretation of the above data, certain considerations should be kept in mind.

(1) The correspondence of Thai word intelligibility to English word intelligibility has not been fully determined.

(2) The relationship of Thai word intelligibility to the intelligibility of connected discourse is unknown.

(3) The English intelligibility scores are perhaps somewhat lower than might be expected. However, there are no data to suggest that the obtained English scores should have been higher than the obtained Thai scores.[15,17,18,19] Experiments reported in the following section provide a comparison with another test of English intelligibility.

(4) The observed differences between U.S. Thai and Bangkok Thai scores, while not large, may be attributed to a number of factors: (a) the two populations of listeners are different; (b) test conditions in Bangkok were less desirable than in Menlo Park; and (c) the Menlo Park listeners were more familiar with the test and consequently did not show an equivalent amount of learning. Some evidence that the latter factor was important was obtained during the test program. Condition C at +12 S/N was the first series of tests administered to the Bangkok Thai listeners after the practice lists. The obtained mean score was 67.4 percent as compared with the mean score of 76.9 percent for the U.S. Thai listeners. The same test series was administered to the Bangkok Thai listeners after the completion of the scheduled tests. The obtained mean score was 77.4 percent, which compares quite favorably with the obtained U.S. Thai score of 76.9 percent.

While data in this research cannot unequivocally establish that Thai speech is more resistant to distortion than English speech, they do suggest this tendency. Additional research reported in subsequent sections tends to support this observation.

The observed differences between Thai and English intelligibility for the identical system configurations shown in Figures 4, 5, and 6 suggested that the attenuated scores for English might be attributable to the particular test (W-22) used in the comparison. In order to be more confident that the observed difference was not an artifact, a second set of English intelligibility tests were administered. In this test program the PB-50's[2] were employed as stimulus items.

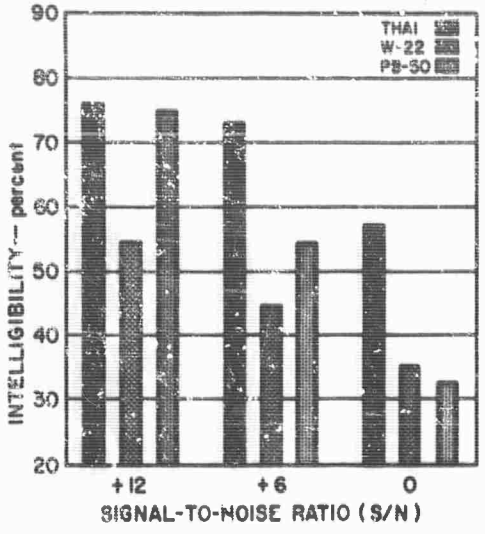
Recordings of the PB-50 word lists (one male speaker) were played through the same system configurations shown in Figures 4, 5, and 6 and at the same S/N ratios outlined in Conditions A through D. The processed tapes were administered to six adult male listeners.

Figure 7(a), (b), (c), and (d) summarize the results obtained in the form of histograms. Data for Thai intelligibility are the mean scores obtained in the earlier tests for both groups of Thai listeners (See Section E). Mean scores for the W-22 word lists are also included.

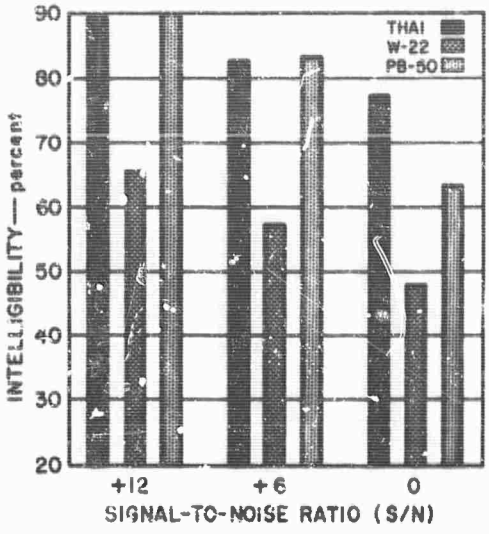
Figure 7(a), (b), (c), and (d) present data that support the earlier observation that Thai tends to be more resistant to distortion than English. This tendency is more marked at the lower S/N ratios. Under Condition B, with a 200-cycle notch from 1175 to 1375 cps, English intelligibility was essentially the same as Thai intelligibility for S/N ratios of +12 and +6 dB. English intelligibility dropped well below Thai at 0 S/N.

In general, the PB-50 test produced higher intelligibility scores than the W-22 test. The exception to this tendency occurred in Condition D. The downward shift in frequency of 150 cps obviously affected the speech of the two speakers differently. The shift severely reduced the intelligibility of the speaker recording the W-22 list. It is interesting to note that the PB-50 words were recorded by a speaker with a rather low habitual pitch, whereas the speaker who recorded the W-22 lists used a somewhat higher pitch.

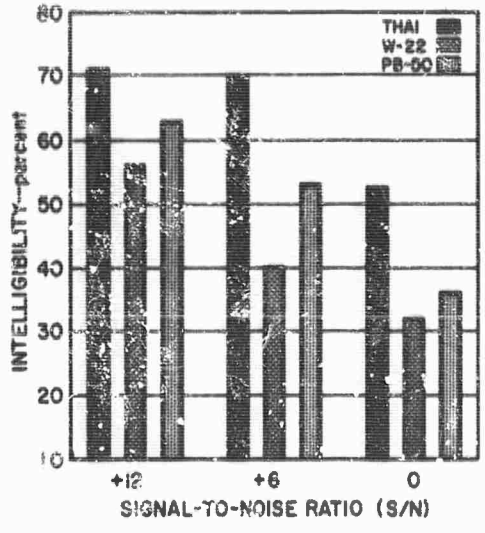
In summary, the measured Thai intelligibility was consistently higher than English intelligibility, as determined by two different tests of English intelligibility for the same S/N ratios. The differences were more marked as the S/N was reduced. The PB-50 test produced higher intelligibility scores than the W-22 test, except when all audio frequencies were shifted -150 cps. This reversal is probably attributable to speaker differences.



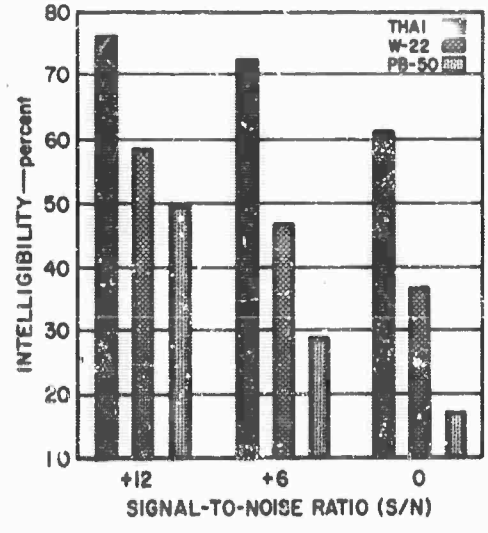
(a) Condition A: 2.1 -kc bandpass centered at 1350 cps.



(b) Condition B: 200 - cycle notch, 1175 - 1375 cps; all audio - bandpassed 300 - 3100 cps.



(c) Condition C: 2.1 -kc bandpass centered at 1350 cps, and all audio frequencies shifted + 150 cycles.



(d) Condition D: 2.1 -kc bandpass centered at 1350 cps, and all audio frequencies shifted - 150 cycles.

FIG. 7 COMPARISON OF THREE INTELLIGIBILITY TESTS AT THREE S/N RATIOS

V ENGLISH-THAI INTELLIGIBILITY TESTS WITH FIELD EQUIPMENT

A. INTRODUCTION

The concluding test effort of the present contract period was the evaluation of Thai intelligibility when Thai was transmitted over actual field equipment. The field equipment employed consisted of AN/PRC-10 radio transceivers. The purpose of this experiment was to compare the performance of the SRI-developed Thai intelligibility test with existing English intelligibility tests when the signal was processed by the radio transceivers. The selected English intelligibility tests were the Central Institute of the Deaf W-22 word lists[2] and the Fairbanks Rhyme Test (RT).[4]

B. PROCEDURE

Magnetic tape recordings of the Thai intelligibility test and the W-22 word lists used in the previous English-Thai intelligibility tests (Section IV) were also used in this series of tests along with five forms of the RT. The RT forms also were included in order to provide a measure of English word intelligibility in addition to the W-22 word lists; all five forms of the RT were used for each test condition.

Figure 8 shows the test setup. The master test tapes were transmitted from an RF screenroom in a laboratory environment. The PRC-10's were connected with RG 58 C/U coaxial cable. Variable attenuator pads placed in the line and were adjusted to yield "good," "marginal," and "poor" transmission conditons. The receiver noise obtained in this manner approximated the transmission noise conditions obtained in the field by means of various transceiver geographic separations. The speech signal variabilities for the Thai intelligibility, W-22 and RT tests were ±4 dB, and ±2 dB, respectively.

Figure 9 shows the modifications made on the H-33/PT handset in order to couple magnetic tape inputs and outputs to the PRC-10 transceivers. These transceivers are portable low-power (0.9 watt), frequency-modulated radios which can be pack-mounted or installed in vehicles to provide voice communication over short distances (3 to 12 miles), depending on terrain, antenna used and other propagation and operational

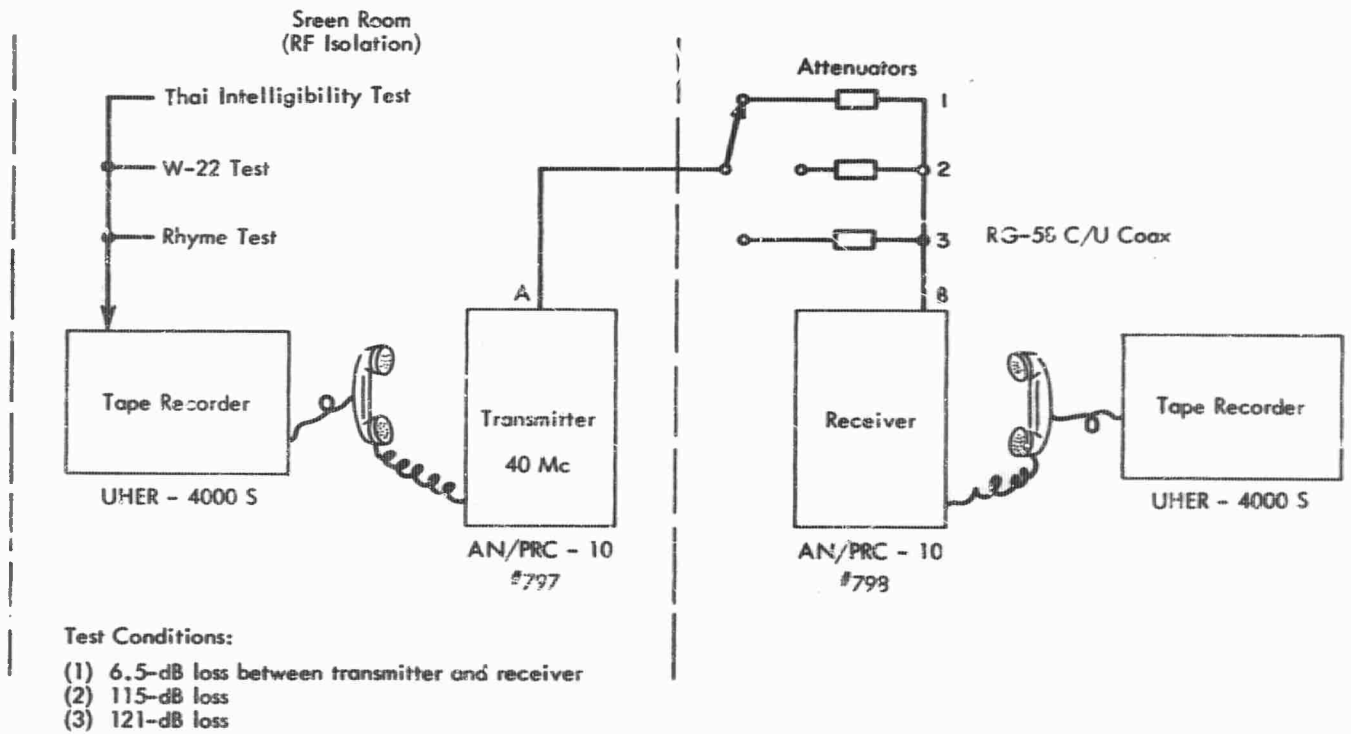
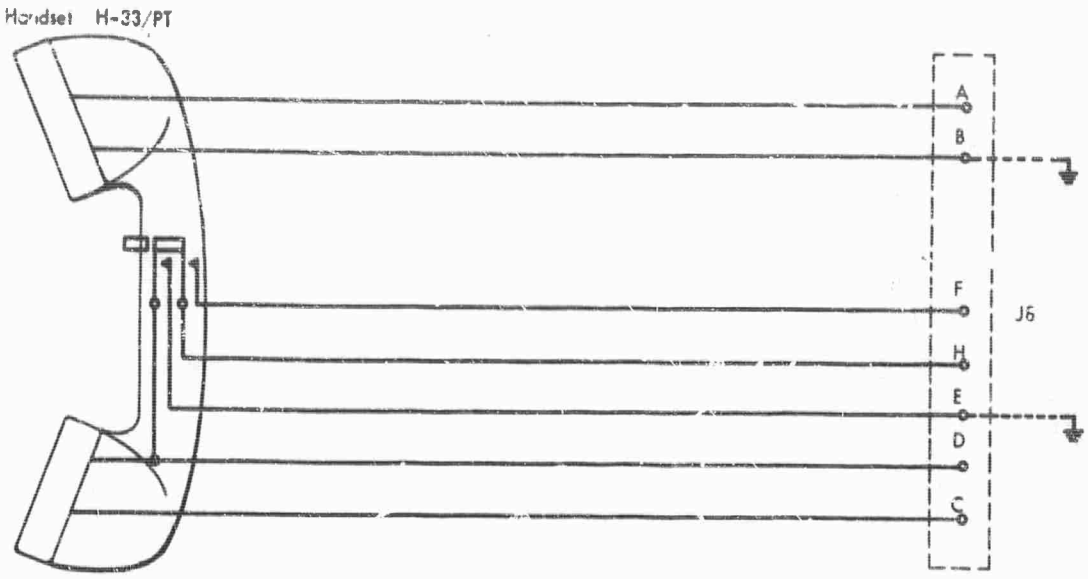
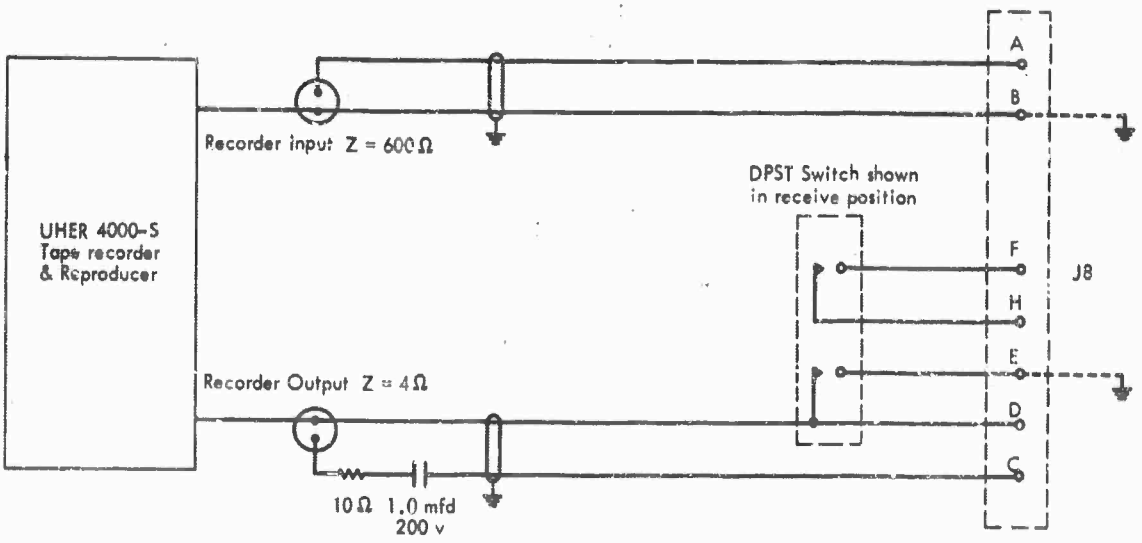


FIG. 8 FIELD TEST SETUP



a. ORIGINAL CONNECTIONS



b. TEST MODIFICATION CONNECTIONS
(Handset Replaced by Recorder)

FIG. 9 TRANSCEIVER INPUT-OUTPUT SCHEMATIC DIAGRAM

variables. The frequency employed for this test series was 40 mc. Transmission at 50 mc was investigated but was eliminated because it was found to be equivalent to the 40-mc operating frequency under the prevailing test conditions, and there was considerable RF interference at the higher frequency. The transceivers were separated by a distance of 30 feet.

C. RESULTS

Table IV shows the mean percentage intelligibility and the standard deviation (σ) of the obtained performance scores for the three transmission conditions investigated. Figure 13 is a histogram of the performance scores. Under "good" and "marginal" conditions, the test scores obtained using the W-22 word lists were approximately 5 percent lower than those obtained using the RT and Thai intelligibility tests. The Thai intelligibility test scores were considerably higher than the English intelligibility scores under the "poor" transmission condition. This finding is in agreement with the data presented in earlier sections of this report; i.e., Thai intelligibility is less affected under adverse communication conditions.

The data obtained during this series of tests is consistent with the patterning of results from the previous experiments undertaken in Sub-Task 4 (Sections II and III). This test series concluded a set of Thai and English intelligibility evaluations which included (1) laboratory tests, (2) tests using simulated field equipment, and (3) tests using actual field equipment.

Table IV

THAI-ENGLISH INTELLIGIBILITY TEST SCORES
FOR THREE TRANSCEIVER CONDITIONS

Mean Scores and Standard Deviation (σ) in %

Listeners	Test		Condition* Good(1)	Marginal(2)	Poor(3)
U.S. Thai	Thai Intellig.	Mean	98.5	37.3	29.8
		σ	1.6	12.0	13.6
University Students	Fairbanks RT	Mean	99.5	38.7	7.4
		σ	1.5	7.3	5.5
	W-22	Mean	94.3	29.1	11.4
		σ	2.8	18.6	4.8

* Conditions

(1) S/N approximately +37 dB
(2) S/N approximately + 3 dB
(3) S/N approximately - 6 dB

} As measured at the receiver audio output and converted from (S + N)/N meter readings.

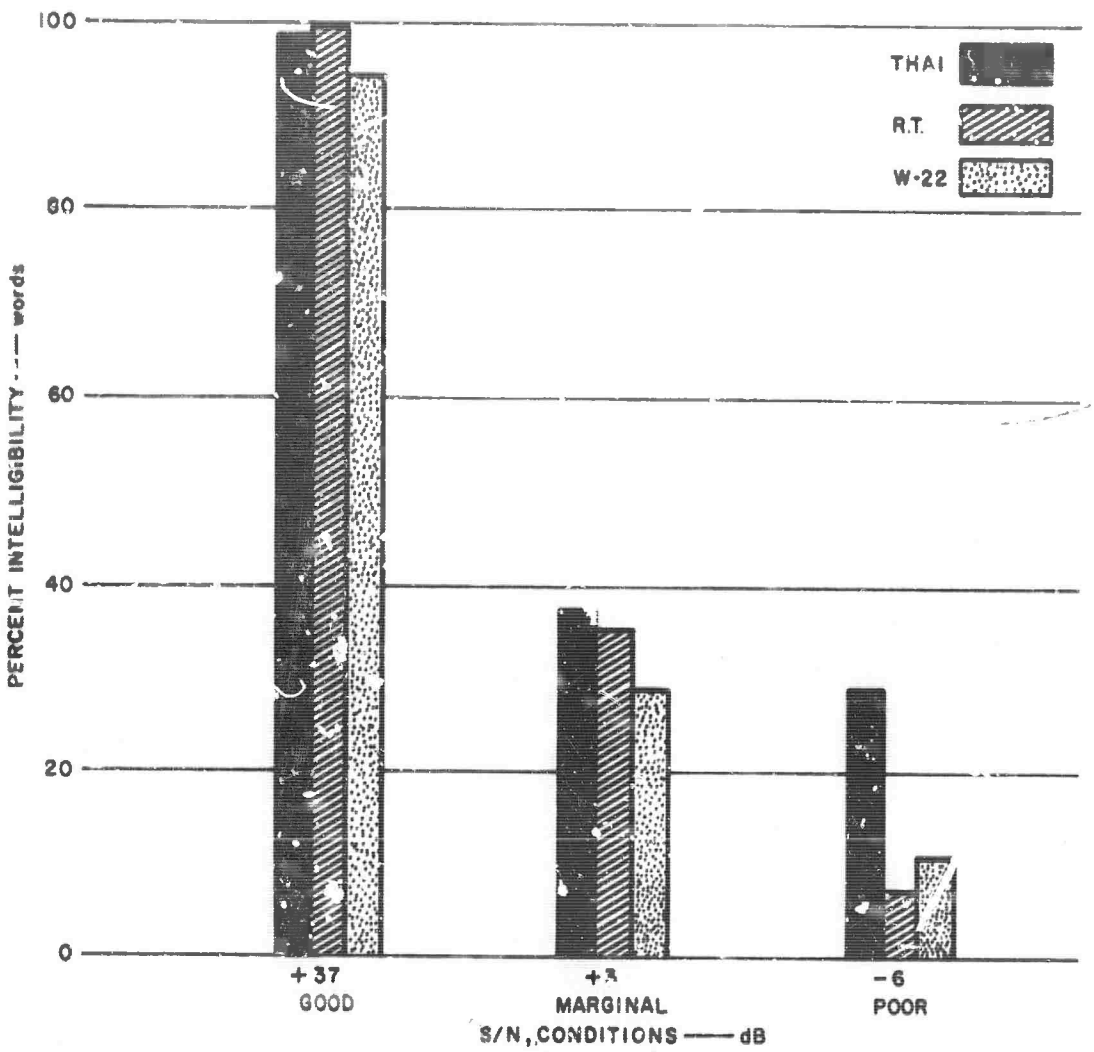


FIG. 10 THAI AND ENGLISH INTELLIGIBILITY SCORES OVER PRC-10 TRANSCEIVERS

VI SUMMARY AND CONCLUSIONS

The objective of Sub-Task 4 was to determine the communication-system implications of Thai speech, with particular reference to any design changes in field equipment which might be necessary in order to transmit and receive intelligible Thai speech. The criterion of acceptable intelligibility was developed by comparing Thai intelligibility to English intelligibility. The research effort was conducted in the following phases:

(1) The phonological characteristics of the Thai language were determined and compared to English. Three major phonological differences were noted: (a) the tone phonemes, (b) the phonemic nature of vowel duration, and (c) the phonemic characteristic of aspiration -- all of the above are characteristic of Thai and not English.

(2) In order to develop a test of intelligibility for Thai, it was necessary to determine the frequency of occurrence of the various phonemes. Various word lists were transcribed into phonemic notation, and the frequencies of occurrences were determined.

(3) A test vocabulary of 250 words was selected from common Thai words and arranged in five phonemically similar test forms.

(4) Three different recordings of the test items were made by native speakers of Bangkok Thai. One master recording was selected for continued use in the test program. Numerous randomizations of the test forms were generated for the continuing effort.

(5) Prepared test tapes were administered to Thai listeners at Menlo Park under selected laboratory conditions. The test signals were submitted to precisely determined amounts of distortion, e.g., reduced S/N and frequency filtering.

(6) A series of tests were conducted to compare Thai and English intelligibility over simulated and real communication systems. The Thai tests were conducted both at Menlo Park and Bangkok.

(7) Additional tests of English intelligibility were conducted to clarify and support the findings of the previous series of tests.

(8) Finally, Thai and English intelligibility scores were obtained for speech signals processed by standard military transceivers.

(9) The scores produced by the developed test of Thai intelligibility were compared with scores obtained using three different tests of English intelligibility under identical conditions.

The above phases of this research effort provide a basis for the following observations. These conclusions, which are subject to the limitations of the designs and methodologies employed, appear justified on the basis of the data obtained during the execution of Sub-Task 4.

(1) A useful Thai intelligibility test has been developed. The intelligibility curves generated by this test display similarities to English intelligibility curves obtained under like conditions.

(2) All of the data obtained in this investigation indicate that Thai word intelligibility is less affected by the reduction of S/N and/or frequency distortion than English word intelligibility. However, word intelligibility scores do not imply simple relations between Thai and English transmitted over equipment used in normal conversation and field operation; more research is required to establish differential effects of syntactical constraints within the two languages.

(3) The Thai intelligibility test, in its present state of development, requires that the same forms be administered under each experimental condition. While the mean scores produced by each of the forms do not differ greatly in magnitude, the differences are statistically significant. Additional research will be required to make the five forms more equivalent.

(4) Certain theories may be offered to explain the greater intelligibility of Thai under adverse communication conditions. Perhaps the most logical explanation is that Thai intelligibility is more dependent on the vowels than the consonants--just the opposite of English. Consonant choices are fewer in Thai than in English, and it is generally accepted that consonants are less intelligible than vowels under conditions of signal distortion.

The research carried out during the current contract period has succeeded in demonstrating that Thai speech does not pose unusual communication systems requirements. Thai intelligibility appears to depend on a somewhat different set of factors than those applicable to English. However, the exact determination of these factors must remain as the objective of further research in this area.

ACKNOWLEDGEMENTS

The author gratefully acknowledges the valuable contributions to this study of Dr. James R. Young, Messrs. R. L. Mock and E. J. Kreul, Mrs. Duagmarn Johnson, Miss Adrianne Blue, Mr. Lionel G. Thompson (Bangkok), Mr. Suchart Puthapong, and the participating Thai college students in the San Francisco Bay Area

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APPENDIX A

THAI INTELLIGIBILITY TEST FORMS

RANDOM FORM

Test #1

1.	มาก	much
2.	ได้	can
3.	กว่า	more than
4.	นี	this
5.	เสีย	broken
6.	อาจ	may
7.	จาก	from
8.	ดู	to look at
9.	ถ้า	if
10.	ผม	I (polite form)
11.	กลับ	to return
12.	แต่	but
13.	สิ้น	to be ended
14.	เข้า	to enter
15.	มุม	corner
16.	ยัง	still
17.	เห็น	to see
18.	ไป	to go
19.	หรับ	six
20.	และ	and
21.	ผิด	wrong
22.	งาน	work
23.	ร่วม	together
24.	ซึ่ง	who
25.	หมอ	doctor
26.	ใด	any
27.	น่า, หน้า	face
28.	วัน	day
29.	ต่อ	to join
30.	นั้น	the
31.	บน	on
32.	เงิน	money
33.	สิ่ง	thing
34.	กัด	to bite
35.	ก็	(particle) with direct meaning in English
36.	เครื่อง	gear
37.	ปาก	mouth
38.	ชุด	set
39.	ฉัน	I (to inferiors)
40.	ไฟ	fire
41.	เพราะ	because
42.	เลิก	to discontinue
43.	โท	two
44.	เอง	self
45.	คือ	namely
46.	ใจ	heart
47.	รบ	to fight
48.	ร้าน	shop
49.	ตั้ง	to set up
50.	มี	to have

RANDOM FORM

Test #2

1.	ไข่	egg	26.	เป็น	to be
2.	ไม่	no	27.	นำ	to lead
3.	กับ	with	28.	เกรง	afraid
4.	เงียบ	quiet	29.	พอ	enough
5.	นะ	(used in requests)	30.	ลูก	child
6.	หมุน	to turn around	31.	ยื่น	other
7.	โดย	by	32.	เดิน	to walk
8.	บาง	some	33.	ขัด	to polish
9.	รู้	to know	34.	เก่า	old
10.	ตอน	part	35.	กลาง	middle
11.	กัน	with each other	36.	จิ	imperative particle of command
12.	รถ	car	37.	จบ	to end
13.	เนื้อ	meat	38.	ซื้อ	to buy
14.	กิน	to eat	39.	ที่	at
15.	สอน	to teach	40.	แข็ง	hard
16.	ฝน	rain	41.	สร้าง	to construct
17.	รายการ	list	42.	ผ่าน	to pass through
18.	ฉีด	to inject	43.	เถอะ	imperative word
19.	จะ	will	44.	โล่ง	open
20.	เรียก	to call	45.	ชาย	male person
21.	ต่ำ	low	46.	ใต้	below
22.	ด้วย	with, by, to	47.	เพื่อน	friend
23.	ลำ	(classifier for boats)	48.	ยิ้ม	smile
24.	หวัง	to hope	49.	เพื่อ	in order to
25.	มอบ	authorize	50.	ห้อง	room

RANDOM FORM

Test #3

1.	จ่าย	to distribute	26.	เหมือน	the same as
2.	แผ่น	surface	27.	ฤกษ	day, hour
3.	ความ	noun forming particle	28.	บุญ	good luck
4.	ด่า	to curse	29.	เกลือ	salt
5.	มัด	to bind together	30.	ซอง	envelope
6.	เอก	one	31.	นาง	woman
7.	ถึง	to arrive at	32.	เดียว	only one
8.	รัก	to love	33.	ปน	to mix
9.	จำ	to remember	34.	ไม่	not
10.	รับ	to receive	35.	การ	affairs
11.	แก่	old	36.	เช่น	such as
12.	โง่	stupid	37.	ปี	year
13.	หรือ	or	38.	ไม้	wood
14.	คะ	madam	39.	ผ้า	cloth
15.	หัว	head	40.	ข้อ	joint
16.	ถอด	to take off	41.	ใส่	to put
17.	สัตย์	truth	42.	ข้าง	side
18.	ฟัง	to listen to	43.	ว่า	to say
19.	คิด	to think	44.	นี่	this
20.	ธาตุ	element	45.	ใคร	who
21.	ส่ง	to send	46.	ผู้	person
22.	ใช่	that's it	47.	อัน	general classifier
23.	บ้าน	house	48.	ติ	to blame
24.	ลง	down	49.	ไกล	far
25.	ลิ้น	tongue	50.	ต้น	base

RANDOM FORM

Test #4

1.	เรื่อง	story
2.	หรั้ง	time
3.	เคย	to be accustomed to
4.	ถาม	to ask someone something
5.	ปลุก	to wake someone
6.	รอบ	around
7.	แม่	mother
8.	กา	teapot
9.	ชื่อ	name
10.	แปลก	strange
11.	เขา	he, she, they
12.	จัด	to arrange
13.	ถาม	to enquire
14.	เช็ด	to wipe
15.	นัก	expert
16.	สั่ง	to order
17.	ร่ม	shade
18.	บ่อย	often
19.	ไหน	where
20.	โดน	to collide with
21.	มา	to come
22.	น้ำ	water
23.	ยา	apply
24.	เหตุ	cause
25.	พิษ	poison
26.	ข้าว	rice
27.	พลาด	to slip
28.	เตะ	to kick
29.	ง่าย	easy
30.	เซ็น	to sign
31.	ท่าน	you
32.	บ้าง	some
33.	ไถ	to plough
34.	สืบ	to investigate
35.	กี่	how many
36.	ที่	occasion
37.	นอน	to lie down
38.	หลัก	stake
39.	อีก	more
40.	ยาว	long
41.	เมีย	wife
42.	ไร่	farm
43.	อัน	general classifier
44.	สืบ	to put on
45.	ตู้	cupboard
46.	ร้อง	to call
47.	สิน	money
48.	ครบ	complete
49.	จน	until
50.	เดือน	month

RANDOM FORM

Test #5

1.	ญาติ	relatives	26.	เพื่อน	friend
2.	ฟ้า	sky	27.	เร่ง	to urge on
3.	ดี	good	28.	ปก	to cover
4.	ซ้ำ	to repeat	29.	เพิ่ง	just now
5.	ร้าย	bad	30.	หญิง	woman
6.	ตัด	to cut	31.	กะ	to estimate
7.	บก	land	32.	เธอ	you
8.	เท่า	equal	33.	ภาค	part
9.	สี	color	34.	ใน	in
10.	จุด	to light	35.	ควร	ought to
11.	คำ	word	36.	หลัง	back
12.	เลี้ยง	to entertain	37.	ครู่	a few minutes
13.	นาน	long (time)	38.	บาท	Baht
14.	นะ	please	39.	ดื่ม	to drink
15.	ยาม	o'clock	40.	โชค	luck
16.	ทรัพย์	property	41.	ชม	to admire
17.	ดื่ม	full	42.	นา	rice fields
18.	งด	to cancel	43.	แรง	strong
19.	เบา	light, soft	44.	น่า	prefix
20.	แนว	column	45.	เมื่อ	when
21.	เจาะ	to bore (a hole)	46.	คุณ	you
22.	ตอน	part	47.	ไหม	question word
23.	ก่อน	before	48.	แฟ้ม	file
24.	โปรด	please	49.	เล็ก	small
25.	เส้น	thread	50.	หิว	hungry

APPENDIX B

DIRECTIVE FROM COTR

November 1964

U.S. Army Electronics Laboratories
Contracting Officer's Technical Representative
C/O OSD/ARPA R&D Field Unit, JUSMAG
APO 146, San Francisco, California

In reply refer to:
AMSEL-RD-NR/4-Bkk 12 November 1964

SUBJECT: Sub-Task 4, Task I, Contract DA 36-039-AMC-00040(E)

To: Senior Representative
Stanford Research Institute
Bangkok, Thailand

1. References:

a. AMSEL-RD-NR/4-Bkk ltr dated 8 July 1964 Subject as above.

b. RDFU MEMO FOR COTR dated 6 July 1964, Incl to Ref 1a, Subject: "Communications Systems Implications of Thai Speech."

c. SRI Memo to COTR dated 13 October 1964 Subject: "Progress Report, Sub-Task 4, Task I."

d. SRI Monthly Letter Report #25 dated 2 November 1964 Contract DA 36-039-AMC-00040(E).

2. In view of the findings indicated in reference 1d that "Thai intelligibility is remarkably similar to English intelligibility under conditions of S+N/N," it is felt by this office and by the RDFU that some immediate tests are warranted to determine if further extensive testing should be conducted.

3. It is directed that the following tests be conducted immediately:

a. Comparison of Thai and English intelligibility when passed through a bandpass of 2.1 kc at 6 db down, 4.2 kc at 60 db down (Shape factor: 2/1) with center frequency of 1350 cycles;

b. Comparison of Thai and English intelligibility when passed through a bandpass of 300-3100 cycles (Standard telephone circuit) with a 200-cycle segment between 1175 to 1375 cycles attenuated 80 db:

c. Comparison of Thai and English intelligibility when passed through a bandpass of 2.1 kc at 6 db down, 4.2 kc at 60 db down (Shape factor 2:1) with center frequency of of 1350 cycles and all audio frequencies shifted +150 cycles. Conditions similar to off-frequency reception of a SSB signal;

d. Repeat test 3c but with audio frequencies shifted -150 cycles.

4. All of the above tests should be performed with the original audio circuits bandpassed at 300-3100 cycles, ±1 db and with S+N/N of 0, +6 and +12 db. The results of these tests are desired by 31 Dec 1964.

5. This letter is subject to the understanding that it does not authorize any change in estimated contract cost, fixed fee, quantity, quality, in delivery schedule, nor in the estimated cost, fixed fee, unit price or total contract price of any sub-contract, and that no action taken by you thereunder will result in any such change.

Kenneth M. Irish, Jr.
Capt. Sig C
COTR, USAEL, Bangkok

c.c.
AMSEL-RD-NR/4, Mr. H. Kitts
AMSEL-PP, Major W. Andrae
ARPA RDFU, Lt. Col. Scoggin

- -

DATE_____

Receipt and acceptance of the above change is hereby acknowledged. The change authorized herein shall be accomplished and will not be used as a basis for a claim for any increase in cost to the Government of the equipment or services involved. Prompt notification of any decrease in the costs shall be furnished to the Contracting Officer.

STANFORD RESEARCH INSTITUTE

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1. ORIGINATING ACTIVITY *(Corporate author)*
Stanford Research Institute
Menlo Park, California

2a. REPORT SECURITY CLASSIFICATION
UNCLASSIFIED

2b GROUP
N/A

3. REPORT TITLE
Task I - Special Technical Report 1
Communications Systems Implications of Thai Speech

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*
Special Technical Report dated June 1965

5. AUTHOR(S) *(Last name, first name, initial)*
Dimmick, Kenneth D.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
June 1965	64	19

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
DA 36-039 AMC-00040(E)	ORD-TR 4240-1
b. PROJECT NO. ARPA Order 371	
c. SEA CORE	9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)* None
d.	

10. AVAILABILITY/LIMITATION NOTICES
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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
None	U.S. Army Electronics Command Communications/ADP Laboratory Fort Monmouth, New Jersey

13. ABSTRACT

The research reported contributes to the understanding of communication system performance with Thai speech, a tonal language having phonemic values in vowel duration and aspiration. Research results are attained by constructing a 250-word Thai intelligibility test in five similar 50-word forms. Laboratory system simulations and a standard military radio system are used to compare English and Thai word intelligibility under identical communication conditions. The research indicates that Thai speech transmission does not imply unusual system requirements. Thai intelligibility seems to depend on factors different from those in English, and further research is required to establish the nature of these factors. (U)

DD FORM 1 JAN 64 1473

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Intelligibility						
Intelligibility Test						
Word Intelligibility						
Thai Speech						
Thai Speech Intelligibility						
Thai Phonology						
Phonemically-Balanced Test						
English-Thai Word Intelligibility Comparison						

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